PB82-224957

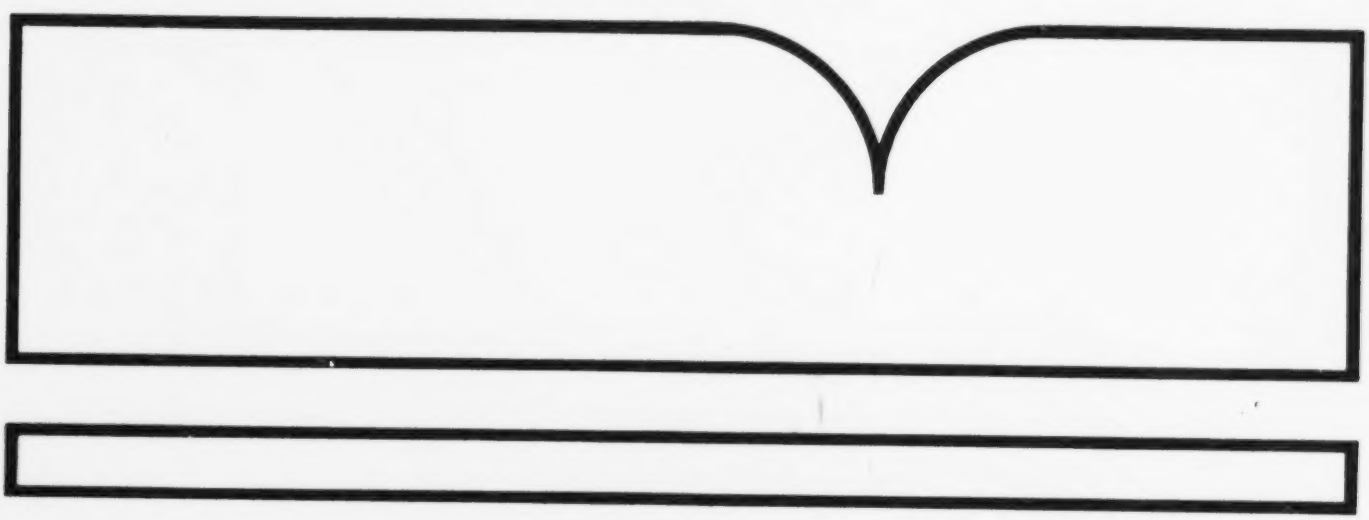
Description and Analysis of Inspection/Maintenance Programs for Oil Fired Central Heating Systems in Switzerland and West Germany

Integrated Energy Systems, Inc.
Chapel Hill, NC

Prepared for

Industrial Environmental Research Lab.
Research Triangle Park, NC

Apr 82



U.S. Department of Commerce
National Technical Information Service
NTIS

PB82-224957

EPA-600/7-82-022

April 1982

DESCRIPTION AND ANALYSIS OF INSPECTION/MAINTENANCE PROGRAMS FOR OIL FIRED CENTRAL HEATING SYSTEMS IN SWITZERLAND AND WEST GERMANY

Prepared by

Robert W. Madler
303 Monmouth Ave.
Durham, N.C. 27701

and

Werner Martin
Integrated Energy Systems, Inc.
307 N. Columbia St.
Chapel Hill, N.C. 27514

EPA Purchase
Order No. 1D2923NASX

EPA Project Officer: Robert E. Hall

Industrial Environmental Research Laboratory
Office of Environmental Engineering and Technology
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-82-022	2.
3. RECIPIENT'S ACCESSION NO. PB82 224957	
4. TITLE AND SUBTITLE Description and Analysis of Inspection/Maintenance Programs for Oil-fired Heating Systems in Switzerland and West Germany	5. REPORT DATE April 1982
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Robert W. Madler and Werner Martin	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Integrated Energy Systems, Inc. 307 North Columbia Street Chapel, Hill, North Carolina 27514	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO. Purchase Order No. 1D2923NASX
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711	13. TYPE OF REPORT AND PERIOD COVERED Final; 2-5/81
	14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Robert E. Hall, Mail Drop 65, 919/541-2477.

16. ABSTRACT The report describes and analyzes inspection/maintenance programs for oil-fired heating systems in Switzerland and West Germany. Inspection programs for oil-fired residential and commercial heating systems were introduced in Switzerland and West Germany in the late 1960s, induced by public complaints about soot and odors. Today, annual or biannual inspections are required by law in both countries. Private or government inspectors perform the inspections, using simple instruments and after being trained for their duties in vocational courses. Both countries have stringent standards for the emission of soot and hydrocarbons as well as for combustion efficiency. Installations not in compliance with the standards have to be adjusted by service technicians within a short time. Significant improvements in air pollution and energy savings have been achieved. Noncompliance with the standards decreased from an initial 40-60% to 5-15% today. The improvement in combustion efficiency (therefore, in fuel oil savings) averages 6%. The reduction of emitted hydrocarbons is substantial, although quantitative information is not available due to the qualitative nature of the inspection procedure. Smoke level is reduced from an average of 3 to 1.5. For oil-fired installations with an average annual oil consumption of more than 1300 gal. (4921 liters)/year, fuel savings exceed the inspection/maintenance costs.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution Heating Fuel Oil Inspection Maintenance Smoke Soot Hydrocarbons Combustion Efficiency	Pollution Control Stationary Sources Switzerland West Germany	13B 13H, 13A 07C 11H, 21D 14G 15E 21B

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 49
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

TABLE OF CONTENTS

INTRODUCTION AND SUMMARY 1
1. Space Heating in West Germany and Switzerland 2
2. Historical Development of Inspection Programs 4
3. Design and Organization of Inspection Programs 5
4. Results of Inspection Programs 9
4.1 Impact on Air Quality 9
4.2 Improvement of Efficiency 14
5. Cost Benefit Analysis 15
5.1 Modeling Procedures 15
5.2 Cost Benefits in Europe 16
5.3 Concept of Marginal Values 18
6. Discussion of Results 25
7. Acknowledgements 27

Appendix A
Summary of Legal Situation in West Germany and Switzerland A-1
Appendix B
Abstracts of Most Relevant Publications Used in the Report B-1

List of Figures

Figure 1 Size Distribution of Oil Heating Installations in Switzerland, 1978 3
Figure 2 Flow Chart for Inspection/Maintenance Programs 8
Figure 3 Results of Inspection Programs in Zurich, Basel, and West Germany as a Whole 10
Figure 4 Marginal Costs and Benefits in Relationship to Installations in Non-Compliance in Europe 17
Figures 5-9 Estimated Marginal Costs and Benefits in Relationship of Percentage Installations in Non-Compliance for the U.S. (1000 gal/yr through 5000 gal/yr) 22-24

List of Tables

Table I	Information on Energy Use in the United States, West Germany and Switzerland in Gallons of Oil Equivalents	2
Table II	Efficiency Standards in Germany and Switzerland	6
Table III	Unqualified Factors Influencing the Performance of Burners	12
Table IV	Unqualified Factors Influencing the Performance of Boilers	13
Table V	Efficiency Distribution of 3000 Oil Heaters	14
Table VI	Violations of Standards of Equilibrium for 1000 Installations	15
Table VII	Costs and Benefits for 1000 Installations as a Function of Inspection Capacity (No. of Annual Inspections)	16
Table VIII	Numerical Values Used for the Calculations of Costs and Benefits of Inspection/Maintenance Programs in the U.S.	19
Table IX	Relationship Between Selected Average Consumption, Number of Installations and Net Benefits per Improved Installation	20
Table X	Total Benefits for the U.S. for Different Consumptions per Installation	21
Table XI	Estimated SO_2 and Particulate Matter Emission Reduction for the U.S. (1978)	26

INTRODUCTION AND SUMMARY

Energy and environmental goals very often create serious conflicts in our modern society. Recently much effort has been devoted to resolving some of these problems. It is especially important to point out areas where steps toward energy and environmental goals can be taken jointly. One such area is energy conservation. This paper focuses on inspection/maintenance programs for residential/commercial heating with oil, an activity which results in simultaneous benefits to energy efficiency and environmental protection. The information presented in the paper about inspection/maintenance programs in West Germany and Switzerland should make it possible to evaluate the potential benefits of such programs in the U.S.

The paper begins with a comparision of U.S. and European energy use and outlines the historic development of oil heating inspection/maintenance programs in Europe. The design and organization of such programs are explained and statistics which were gathered since the introduction of the programs are presented. A cost benefit analysis for the programs in West Germany and Switzerland is presented and an estimate for the U.S. is made.

Between one quarter and one half billion dollars could be saved annually by implementing an oil heating inspection/maintenance program in the U.S. The net benefit would go to the oil consumer. The SO_2 emission for residential and commercial oil heating could be reduced by 2.5%.

1. Space Heating in West Germany and Switzerland

Oil is the main source for space heating in both West Germany and Switzerland, providing two-thirds of the total space heating energy. Natural gas, electricity, coal, and wood share the remaining percentage. Solar energy, other than direct gain through windows and indirect gain through heat pump systems, still makes only a negligible contribution.

Table I points out some of the differences between the energy use in West Germany and Switzerland and the U.S. The U.S. has a high percentage of its space heating requirements supplied by natural gas and therefore a relatively low contribution is made by oil. The differences in total energy consumption per capita can be explained by two factors. The U.S. and West Germany have a much higher production of energy intensive products than does Switzerland. Also, the U.S. has a very high per capita consumption of energy for transportation, mainly due to longer commuting distances, sprawl development, and fewer mass transit systems.

The technology of oil heating systems is similar to that found in the U.S. Nozzle-type burners are used. Central heating boilers are the main type of heat exchangers because hydronic heating systems are prevalent. Unlike in the U.S., furnaces are not common in space heating applications.

Figure 1 represents the equipment size distribution in Switzerland. The large portion of small equipment becomes apparent. The median size burner has a capacity of 1.7 gal/hr.[6] In Switzerland such an installation would be in operation during 1800 hours of the 180 day average heating period, consuming an average of 3000 gallons of oil. Unfortunately, such information is not available for West Germany.

In Switzerland the average sulphur content in heating oil was 0.36% (average between 1977 and 1979). In West Germany the value was around 0.4%.

Table I. Information on Energy Use in the United States, West Germany, and Switzerland in Gallons of Oil Equivalent.

Country	Per Capita Total Energy Consumption (calc. in gallons of oil)	Per Capita Total Energy Consumption for Space Heating (calc. in gallons of oil)	Percentage of Space Heating Energy Consumption Provided by Oil
United States	1900[1]	380[2]	33[5]
Switzerland	552[1]	280[3]	70[3]
West Germany	974[1]	258[4]	60[4]

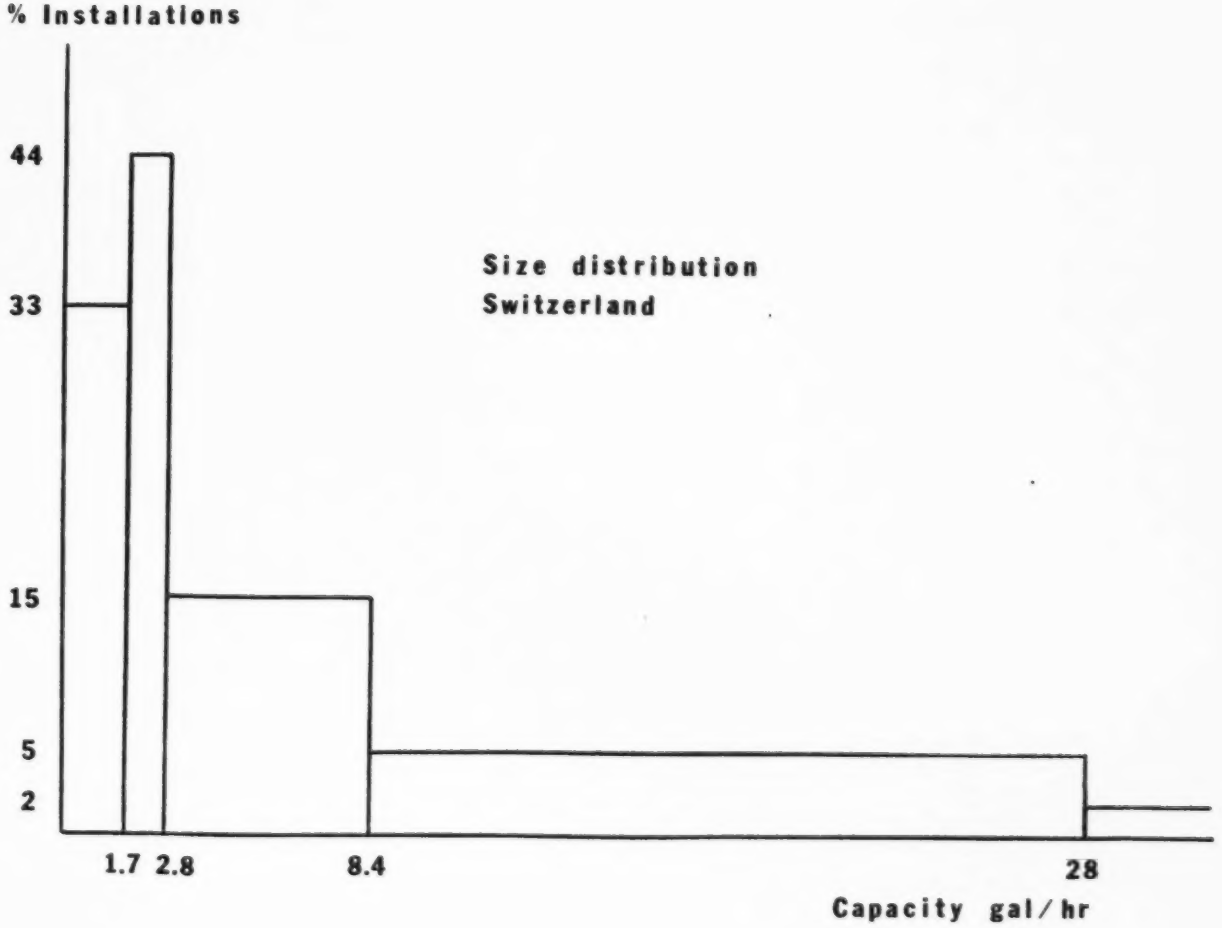


Figure 1. Size Distribution fo Oil Heating Installations in Switzerland, 1978.

2. Historical Development of Inspection Programs

With a sharp increase in oil consumption for heating purposes in the decade from 1950 to 1960 the public became aware of air pollution emitted by oil heating. Along with the increased population density in urban areas (more than 200,000 inhabitants/square mile) came an increase in public awareness of the amount of physical air pollution by odors and soot emitted from heating chimneys. When problems arise, Europeans typically assign the responsibility for solving them to their local or regional governments. In the case of air pollution, complaints emerged and were directed to the local Public Health Departments. Unfortunately, nobody kept a record of the number of complaints two decades ago. Today, the treatment of public complaints is a widely recognized managing tool for air pollution control.[7] We can therefore only guess how many complaints were necessary to trigger action. The Public Health Department of the City of Zurich (Switzerland) decided in 1964 to introduce an inspection program for residential oil heating installations.[8] Although simple in design and equipment, the inspections proved to be effective. The idea of governmental inspections for oil heaters spread rapidly to many other cities in Switzerland and Germany, and is now also well accepted in rural areas in the two countries. Under fire protection regulations the maintenance of heating equipment has been regulated since the last century. With the new oil heating inspection, air pollution control and later energy conservation have become the new focal points.

3. Design and Organization of Inspection Programs

3.1 Technical Equipment for Inspections

At the beginning, the inspectors had only a Bacharach smoke pump for checking the smoke level. The inspectors were advised to watch for a yellow color on the smoke-filter papers. This color indicates traces of partially burnt or unburnt oil. No information was collected about the odors emitted.

Today, the equipment has become more sophisticated. The Bacharach pump was replaced by a powered sampling instrument. The filter paper has grown in exposure area, and the volume of air pumped through has increased proportionally. Besides reducing sampling errors with more precise sampling, the larger filter paper also allows for a simple chromatographic procedure for testing oil traces. A drop of a solvent (alcohol, xylol) placed in the middle of the paper flushes any traces to the outside rim, where they are concentrated and easily detectable by a yellowish color.

In addition to this equipment for air pollution sampling, inspectors today check combustion efficiency as well. This is usually done by measuring carbon dioxide and stack temperature to determine energy loss through the stack.

3.2 Standards

Air Pollution: In Switzerland a smoke level of two or less on the Bacharach scale is mandatory.[9,10] A smoke level of three or less is mandatory in West Germany. No visible traces of oil on the filter paper are allowed. If an installation fails to meet either standard, the owner is legally obligated to have the installation serviced by a licensed service technician. If the inspection following this service still reveals non-compliance, the installation has to undergo a fundamental improvement, usually consisting of replacement of the burner, or the boiler; sometimes even a new stack has to be built to deliver sufficient draft for proper functioning of the installation.

Combustion Efficiency: West Germany[10] has legal efficiency standards. In Switzerland federal efficiency standards[11] are set as guidelines. Several state and local governments have already declared these standards mandatory. The standards expressed in percentage efficiency are summarized in Table II.

Table II. Efficiency Standards in Germany and Switzerland.

Capacity in gal/hr	Country	installation date, efficiency in %		
		1978 or earlier	1979-1982	after 1982
0 - 1.7	Switzerland	84	87	87
1.7 - 8.4		86	88	88
> 8.4		88	89	89
0-0.06	Western Germany	82	84	86
0.7 - 1.4		83	85	87
1.4 - 3.3		84	86	88
> 3.3		86	87	89

3.3 Organization of the Inspection Programs

Whereas a federal law regulates the organization of oil heating inspection in West Germany, in Switzerland the state and local governments are responsible for introducing and enforcing these requirements. There are two fundamentally different ways of executing the inspections:

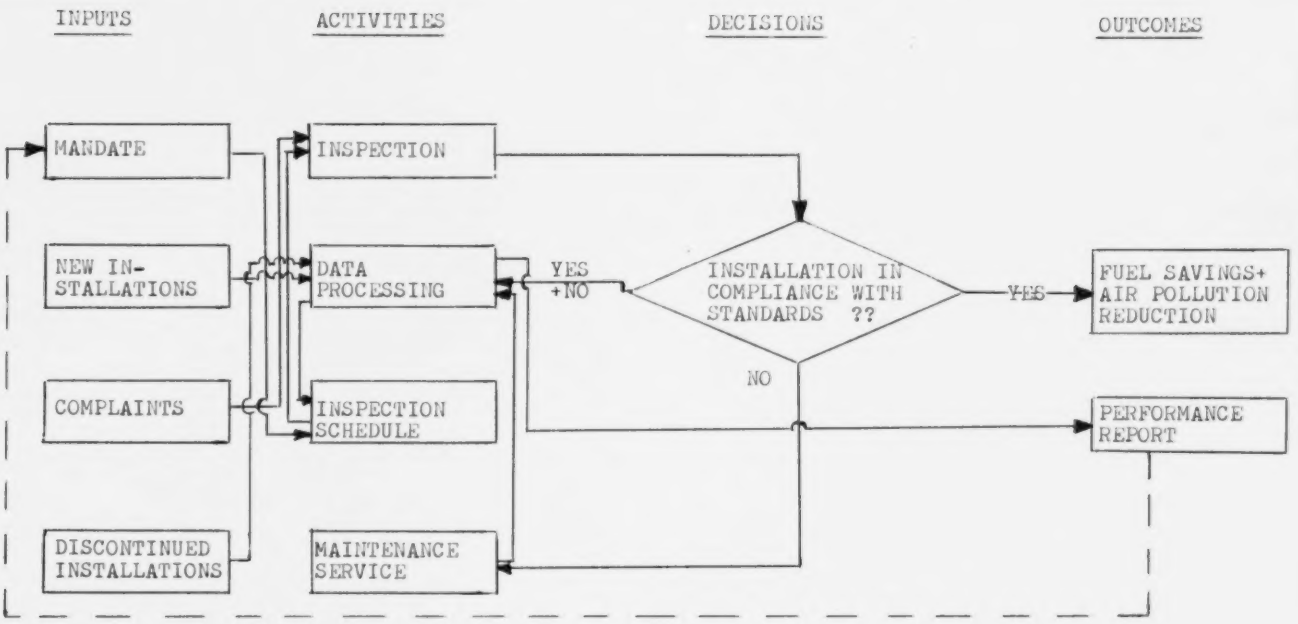
A) inspection by government employees, or

B) inspection by private enterprise

A) The idea of government employees having the right to inspect something in a private home may be strange to Americans. In European countries many examples of government intrusion in spheres considered to be private in the U.S. can be found. The public does not reject such intrusions in the case of oil heating inspections. In fact, in about half of the existing inspection programs in Switzerland, the task is performed by government employees. There are two advantages when the government conducts the inspections. The government is neutral and does not favor any brand names or manufacturing companies. There are three different charge systems in use. No charge at all, charge of full cost to home owners, and charge only in case of non-compliance. Second, where the government is responsible for inspections, detailed statistics are usually available about the benefits and therefore the success of the program.

B) Inspections are conducted by private persons in Germany. The local chimney sweeps are in charge of inspecting the heaters when they do their conventional job. In both Germany and Switzerland, homeowners are required to have their boilers, furnaces, and chimneys cleaned at least once a year by a licensed chimney sweep. Combining the inspection with the cleaning task has obvious economic synergies. The legal assignment of inspections to chimney sweeps depends, of course, on the willingness of the professionals, who are usually organized in guilds or trade associations, to perform the task.

The flow chart presented in Figure 2 shows the general organization of inspection/maintenance programs in Switzerland and West Germany. Both governmental and private inspectors are required to attend an instruction program lasting from one to several weeks. In addition, relevant instructional programs are required when new equipment or new techniques are introduced.



Explanations to Flow Chart:

MANDATE:	legal assignement to inspect oil fired heatings, usually the law requires all installations to be inspected in a given period, eg 1,2, or 3 years
DATA PROCESSING:	done either electronically or by hand. New and discontinued installations have to be recorded. Record of all activities and the decision result is kept. Delivers the inspection schedule, which installations to inspect when. A performance evaluation is reported end of each period.
INSPECTION SCHEDULE:	Assigns inspectors to installations to inspect in a time period. Many programs have daily or weekly assignements.
INSPECTION:	Activity of checking, if the installations complies with standards.
COMPLAINT:	Information from the Public about odors or visible soot, initiate an out of schedule inspection with priority
MAINTENANCE SERVICE:	Activity required by inspector, if checked installation is found noncomplying. Some programs require a second inspection after servicing the installation
COMPLIANCE DECISION:	done by the inspector immediately, according to the standards given to him
PERFORMANCE REPORT:	allows in its most basic form to evaluate the number of noncomplying installations found in each period. Some programs report the percentage of noncomplying installations related to additional characteristics, like age, capacity, brandnames etc.

Figure 2. Flow Chart for Inspection/Maintenance Programs.

4. Results of Inspection Programs

4.1 Impact on Air Quality

When inspection/maintenance programs were first introduced, the rate of rejections varied between 40 and 60 percent. These high percentage figures were mainly due to a lack of correct burner adjustments. Technicians installing the equipment were not properly trained and homeowners were not aware of the implications of an incorrectly adjusted burner in terms of energy use and air pollution.

During the first few years of the inspection programs, a sharp decrease of violations occured.[12,13,14] Figure 3 summarizes the results achieved over five to eight inspection cycles (1 year in Basel and West Germany, 2 years in Zurich). The violation percentage reaches an equilibrium level after several years. In the case of annual inspections the equilibrium level is about 9%. With biannual inspections (Zurich) the equilibrium level appears to be higher. A theoretical model based on a two-level Markov process supports this hypothesis.[17] The model predicts an equilibrium level of 9% violations for an annual inspection cycle, and 17% for a biannual inspection program.

Data gathered from inspection and maintenance programs indicates that there is an interdependence between the violation rate and equipment size and the violation rate and equipment age.[12,13,14] There was a much lower violation rate for larger equipment. This is attributed primarily to better maintenance and operation of large equipment and the resulting lower emissions of particulates and unburnt hydrocarbons.

As for age as an independent variable, the results are split into age of burner and age of boiler. Poor performance of newer burners is explained mostly by adjustment problems in the first months of operation while older burners show a steadily decreasing performance with increasing age. Also older boilers were designed mostly for coal as fuel and had square shaped flame chambers. Newer boilers are designed for oil burners and have a tube-shaped flame chamber, allowing an even thermal density function around the flame and higher efficiency.

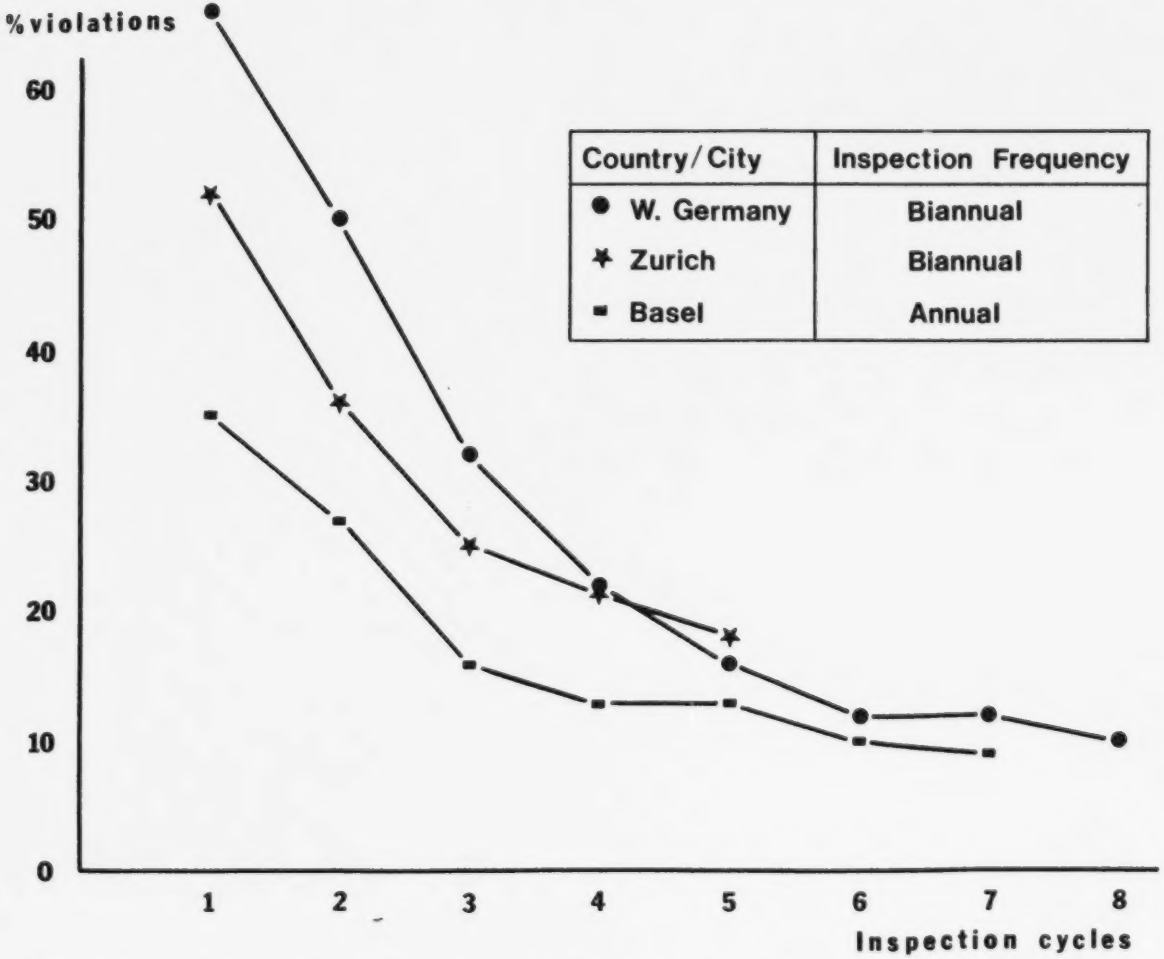


Figure 3. Results of Inspection Programs in Zurich, Basel, and West Germany as a whole.

The total benefit in air pollution reduction for the city of Zurich[15] is estimated to amount to:

1% of total SO_2 emissions	through improvements in energy efficiency
60% of total soot emissions	through improvements in combustion
25% of total hydrocarbon emissions	

Last year, the city of Zurich published a detailed report on the rate of non-compliance for each major brand of oil-burner and boiler.[8] Since some of these brands are marketed in the U.S. as well, the results are presented in Tables III and IV.

Table III. Independent Variables and Non-Compliance Rates for Oil Burners.

Independent Variables / Brand Names	number of installations	Evaluation (non-compliance percentage)
		excellent / good / satisfactory; 0 5 10 15 20 25 30 35 40 45 50%
Accumat	94	
Busco	1077	
Cuénod	1184	
Delco	56	
Diener	1075	
Elco	3847	
Elektro-Oil	150	
Fag	535	
Flamma	135	
Gilbarco	2096	
Hälg	301	
Monarch	82	
Oertli	6308	
Oil-O-Matic	786	
Oil-Therm	3098	
Purflam	221	
Quiet May	119	
Ray	114	
Six Madun	585	
Sun Ray	131	
Swiss Therm	259	
Thermo Matic	111	

Unquantified factors influencing the performance of Burners:
-capacity
-design of boiler combined with burner
-service contract
-model year.

Table IV. Independent Variables and Non-Compliance Rates for Oil-Fired Boilers.

Independent Variables / Brand Names	number of installations	Evaluation (non-compliance percentage)
		excellent: 0 5 10 — good: 15 20 25 — satisfactory: 30 35 40 45 50%
Accumat	120	
Buderus	487	
Compass	216	
CTC	930	
De Dietrich	96	
Hildener	100	
Hoval	3543	
Idag	354	
Ideal	5830	
Klus	1422	
Minitherm	221	
Pieren	155	
Strebel	5760	
Sulzer	425	
Ygnis	564	
Zent	2158	

Unquantified factors influencing the performance of Boilers:
-capacity
-design of boiler
-service contract
-model year.

4.2 Improvement of Efficiency

After the first oil crisis in 1973, government officials in charge of the inspection programs started to collect efficiency data. Surprisingly, a substantial increase in the average efficiency was found.[14,15,16] A comparison of installations violating the air pollution standards and ones in compliance showed a difference in efficiency of about 6%. Most installations had a low carbon dioxide concentration in the stack gases, which may have been the reason for the rather large improvements.

In West Germany, the average improvement was from 77.5% to 83.1%.[13] In Zurich, Switzerland, only a difference of 6% is reported, with no indication of a base value.[16] The author instead gives a distribution of the efficiency of a sample of 3000 inspected installations as shown in Table V:

Table V. Efficiency Distribution of 3000 Oil Heaters.

Efficiency in %	Number of Installations
< 80	213
80 - 85	563
85 - 90	1767
> 90	457

5. Cost Benefit Analysis

5.1 Modeling Procedures

In order to relate costs and benefits of inspection programs, a model has to be found which describes the relationship between the inspection capacity (number of installations inspected per year) and the achievable equilibrium levels of violations after several inspection cycles. Regression analysis does not prove to be a useful model because it underestimates the percentage of violations with increase of inspection cycles. The capacity is assumed to be the most relevant cost factor. The equilibrium level depends on the number or percentage of installations working efficiently after implementation of an inspection program and on approximately 50% of the installations being in good condition initially.

Such a model was found by applying a simple two-level Markov process with a transition probability between the two levels.[17] The transition probability is the deterioration or failure rate of oil heaters. It was determined from the data presented in Figure 2 and has a numerical value of 10% per year.

Applying this model, the equilibrium levels of Table VI were calculated.

Table VI. Violations of Standards at Equilibrium for 1000 Installations.

Inspection Capacity, Installations per year	Time for 1 Full Inspection Cycle (in years)	Number of Installations in Non-Compliance
100	10	500
200	5	333
300	3 1/3	250
400	2 1/2	200
500	2	167
600	1 2/3	143
700	1 3/7	125
800	1 1/4	111
900	1 1/9	100
1000	1	91
2000	1/2	48

To confirm the results a computer simulation was done.

5.2 Cost Benefits in Europe

In order to justify the program, the benefits should exceed the cost. For European inspection programs the costs are approximately $25 per inspection and $75 per maintenance service. Inspection costs occur to all installations, whereas maintenance service costs occur only in cases of non-compliance. The benefits are only quantifiable for the reduced oil consumption due to maintenance. For the cases where maintenance is necessary, an average savings of $167 has been observed. Continuing our example with the 1000 installations from Table IV, the costs and benefits presented in Table VII can be generated by applying the model from 5.1.

Table VII. Costs and Benefits for 1000 Installations as a Function of Inspection Capacity (No. of Annual Inspections).

Inspection Capacity	Costs of Inspections In $	Number of Installations Improved	Savings after Maintenance Costs	Net Profit In $
200	5,000	167	15,500	10,500
300	7,500	250	23,500	15,500
400	10,000	300	28,000	18,000
500	12,500	333	31,000	18,500
600	15,000	357	33,000	18,000
700	17,500	375	34,500	17,000
800	20,000	389	36,000	16,000
900	22,500	400	37,000	14,500
1000	25,000	409	38,000	13,000
2000	50,000	452	42,000	8,000

Although our example takes into account only 1000 installations of average capacity, the benefits are substantial and reach a maximum at a biannual cycle. The benefit of air pollution reduction is not accounted for. Since the program produces a net benefit from fuel savings alone, air pollution benefits do not have to be expressed in monetary terms.

Before any potential benefits in the U.S. can be estimated, the results of the European inspection programs have to be converted to marginal values. This conversion is shown in Figure 4.

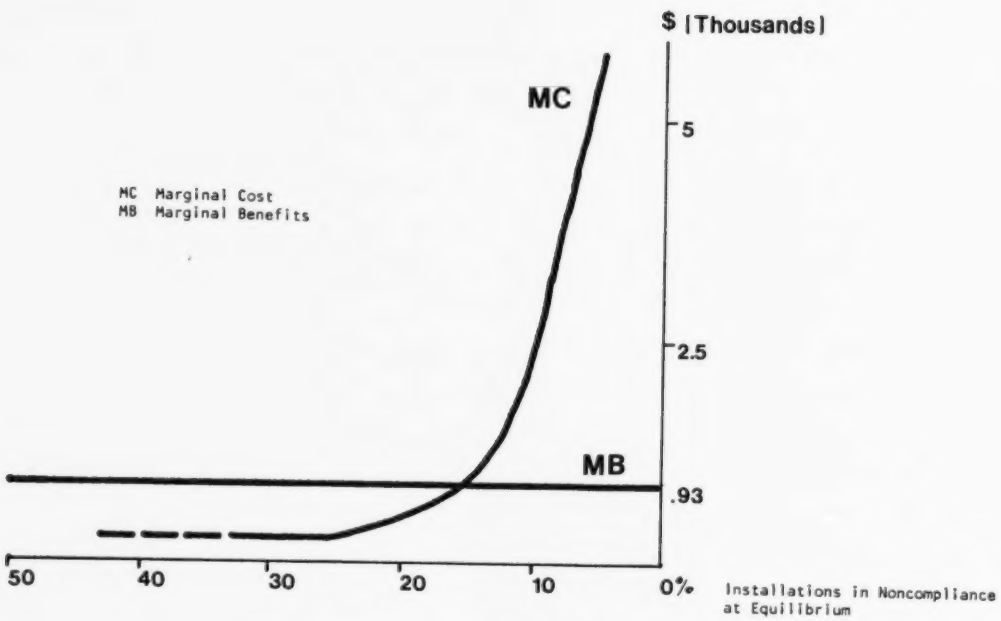


Figure 4. Marginal Costs and Benefits in Relationship to Installations in Non-Compliance in Europe. Values are based on 1000 Installations.

5.3 Concept of Marginal Values

In economics, these names are given for the first derivatives of cost or benefit functions. The literal meaning may be best described as: increase or decrease in benefit or cost per unit. In our case the marginal benefit is the benefit gained by improving one additional percent of all installations and the marginal costs are the costs to make those improvements.

The economically desirable profit maximization occurs where marginal benefits equal marginal costs. In other words, if the costs for improving one additional installation are greater than the benefit gained by this improvement, this improvement reduces the total profit. If costs for improving one additional installation are lower than the savings, the overall profits still increase. In the case where the gain and the cost for improving one additional unit are equal, we are at an optimum.

5.4 Estimation of Cost-Benefit Analysis of a U.S. Inspection Program

To transfer our findings to the U.S. environment, we have to assume similar circumstances as those which occur in Europe. This relates in particular to:

- failure rate of heating equipment
- percentage of inefficiently operating and polluting installations before the start of inspection programs (European result: 50% of all installations are below the standards)
- inspections and service methods are similar and produce identical results

In order to estimate costs and benefits of a U.S. inspection/maintenance program, the numerical values in Table VIII are used. The only value taken from European experience is the 6% overall fuel savings resulting from such a program. Only a representative survey can prove whether this figure is correct for the U.S. circumstances.

Table VIII. Numerical Values Used for the Calculations of Costs and Benefits of Inspection /Maintenance Programs in the U.S.

Parameter	Values	Source
fuel oil price	1.21 $/gal	market price as of March 1981
U.S. fuel oil consumption for residential and commercial space heating	2.76×10^{10} gal/yr	ref. 2, 5
increase in efficiency per improved installation = fuel savings	6%	ref. 13, 14
SO_2 emissions from residential and commercial oil heating	1160×10^3 tons/yr	ref. 18
ditto, particulate matter emissions from residential amd commercial oil heating	80×10^3 tons/yr	ref. 18

Unfortunately, no information about average oil consumption per installation or about the number of installations in the U.S. was available. Knowledge of either one of these parameters would make it possible to calculate the other. The total annual oil consumption for residential and commercial heating purposes is known.

To by-pass this lack of information, a sensitivity analysis approach was chosen. The oil consumption was varied between 1000 and 5000 gal/yr. These values should cover the true, unknown average consumption. We know from Switzerland that the average consumption is 3000 gal/yr. Furthermore, this variation includes the lower end of the break even point, where costs and benefits are equal.

To estimate the potential benefits of inspection programs in the U.S., we have to assume inspection costs of approximately $20, and maintenance service costs of $60. The inspection cost is an estimate based on European experiences. It is based on the number of inspections per inspector, about 1500 to 2000 per year, and the U.S. wage level including overhead costs. The $60 value for maintenance takes into account the longer working time compared to inspections and replacement of minor parts, like oil filters, nozzles, etc. Service crews in North Carolina actually charge $60 per maintenance job.

To calculate the benefits we use the 6% savings achieved per average installation and the current market price for fuel oil. The net benefit per improved installation is the difference between the savings and the required maintenance service to achieve those savings. Table IX shows the results for the five different average consumption rates chosen.

Table IX. Relationship Between Selected Average Consumption, Number of Installation and Net Benefits per Improved Installation.

average consumption per year and installation, gal	net benefit per year and installation, $	number of installations in the U.S.
1000	13	27.6×10^6
2000	85	13.8×10^6
3000	158	9.2×10^6
4000	230	6.9×10^6
5000	303	5.5×10^6

The calculation of the number of installations is based on the total oil consumption for residential and commercial space heating of 2.76×10^{10} gallon per year as mentioned in Table VI. This amount divided through the average consumption results in the numbers given in Table IX.

For calculating the total benefits for the U.S., achieved by inspection programs, we first determined the optimal inspection schedules from Figures 5 through 9. The percentage taken at the intersection of marginal costs and marginal benefits is the equilibrium non-compliance rate for the optimal inspection schedule in each case. The total benefits are now calculated by multiplication of the number of installations improved through the program (non-compliance rate from figures versus non-compliance rate initially equal to 50%) with the net benefits from Table IX. The costs for the necessary number of inspections are subtracted. The relationship between the equilibrium non-compliance rates and the required number of inspections are developed from Table IV.

Depending on the average consumption per installation, total net benefits can be derived (Table X).

Table X. Total Net Benefits for the U.S. for Different Consumptions per Installation.

average consumption	net total benefit in $ millions
1000 gal/yr	none*
2000 gal/yr	252
3000 gal/yr	417
4000 gal/yr	512
5000 gal/yr	573

*slight loss calculated, no numerical value possible because it is out of modeling range

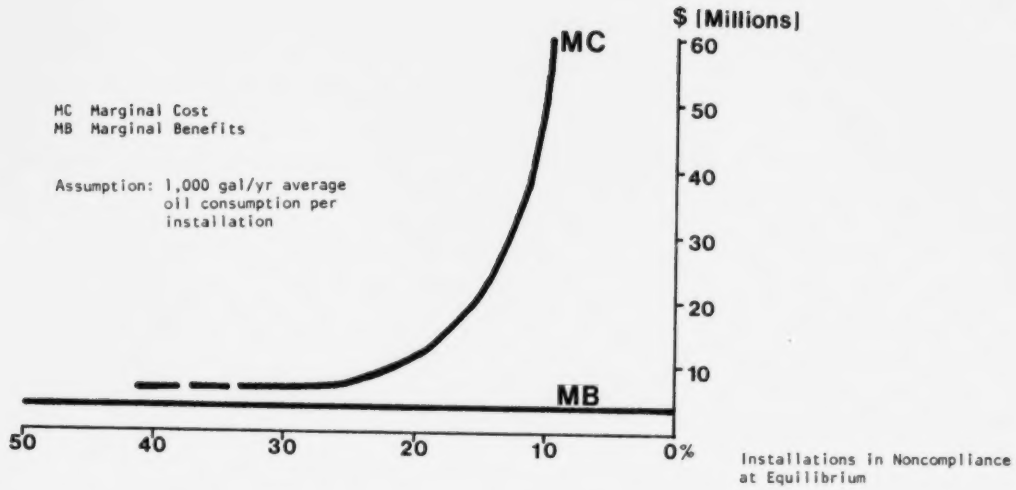


FIGURE 5.

Estimated marginal costs and benefits in relationship of percentage of installations in non-compliance for the U.S.

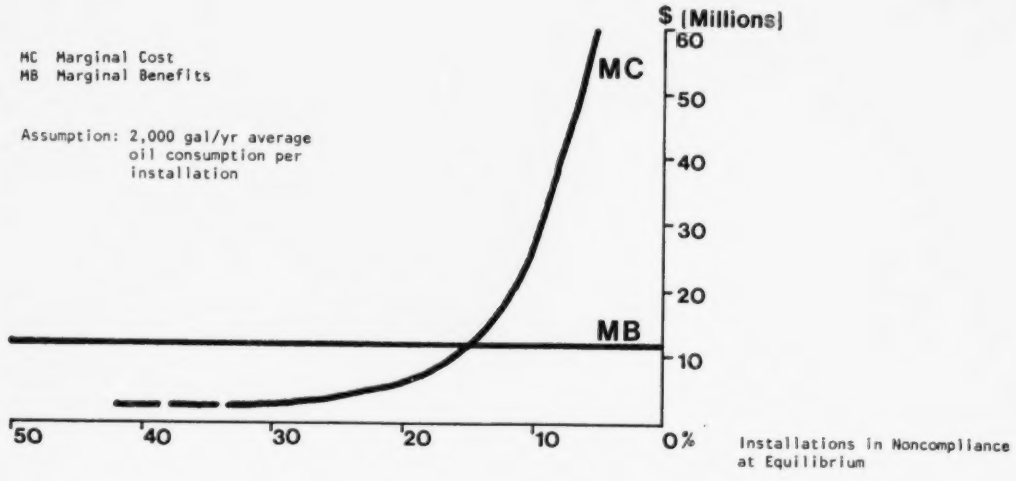


FIGURE 6.

Estimated marginal costs and benefits in relationship of percentage of installations in non-compliance for the U.S.

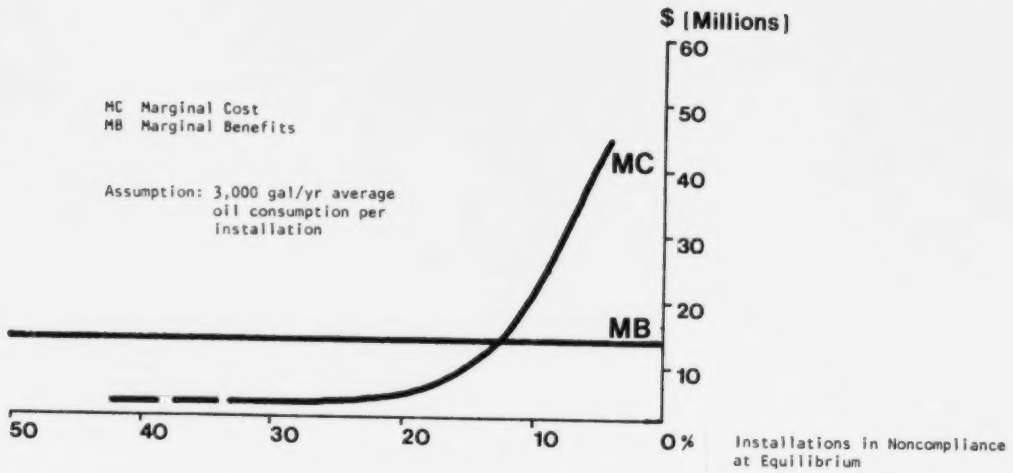


FIGURE 7.

Estimated marginal costs and benefits in relationship of percentage of installations in non-compliance for the U.S.

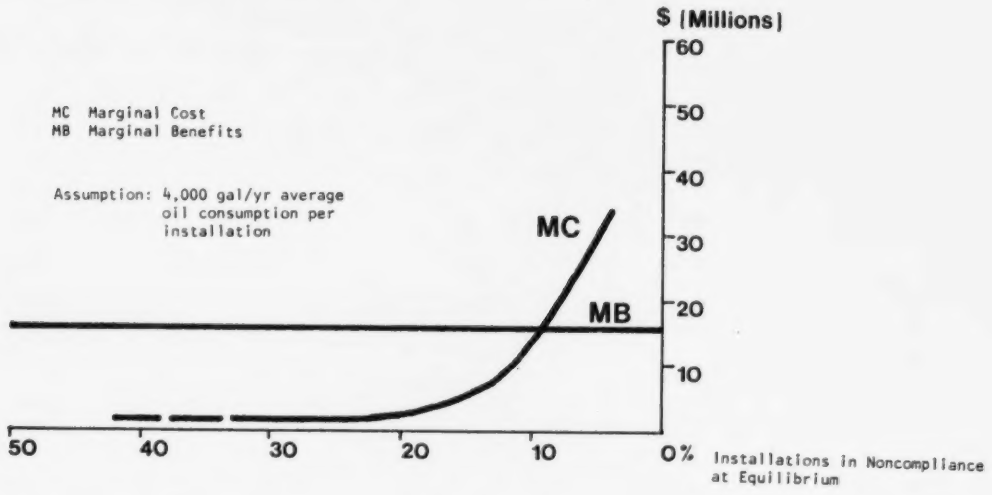


FIGURE 8.

Estimated marginal costs and benefits in relationship of percentage of installations in non-compliance for the U.S.

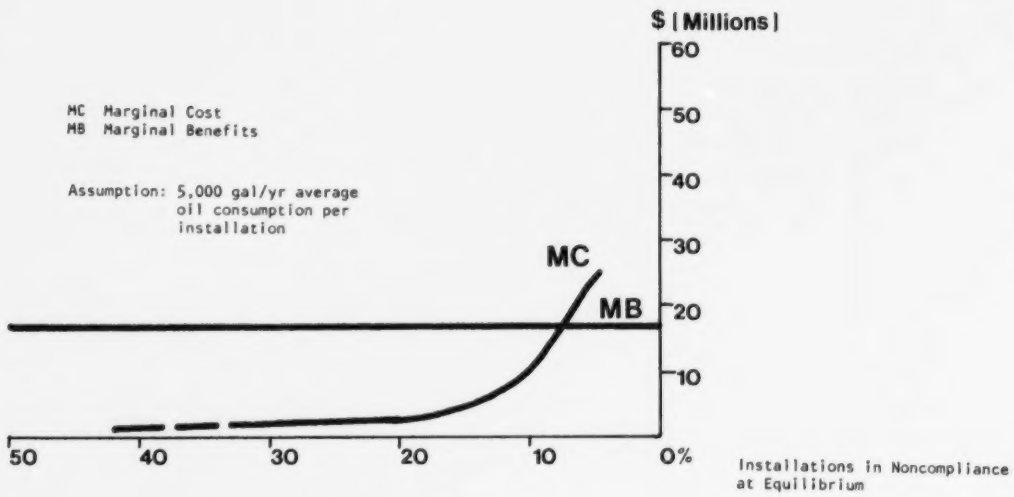


FIGURE 9.

Estimated marginal costs and benefits in relationship of percentage of installations in non-compliance for the U.S.

6. Discussion of Results

Inspection programs for oil-fired central heaters are (under a wide range of assumptions) economically profitable. In the calculations made for Figures 5 through 9, the average consumption per installation was varied in a ratio of 1:5. For the lowest consumption rate a net loss occured. The calculation of break even point consumption rate is interesting. The break even point criterion is the following:

Net benefit (per installation) = inspection cost (per installation)

Assuming inspection costs of $20, we calculate the consumption rate for which the new benefit equals $20. The so called break even point consumption rate turns out to be 1333 gal/yr. This result can be interpreted as follows: An inspection program should only be aimed at installations with annual consumption rates greater than 1333 gal/yr. To cover smaller installations will not be profitable to date.

The calculation of the air pollution reduction follows considerations similar to the ones for the benefit calculations. Because of the more qualitative nature of the air pollution information known, we make some simplifications. We assume that overall only 40% of all installations will experience a pollution emission reduction after implementation of inspection programs. These 40% are derived from equilibrium levels in Figures 5 through 9. These improved installations emit 6% less sulphur dioxide, exactly the same reduction as oil consumption.

The reduction of particulate matter emissions is rather difficult to derive from improvements documented in smoke number measurements. There is no linear relationship between smoke number and particulate matter mass. For every source the relationship between the two is different because smoke numbers are an optical indicator dependent on particulate size distribution, whereas mass is not influenced by particle sizes.

According to the information presented by Davids[13], 40% of all installations are operated at CO_2 levels of 8% and less. The average CO_2 value for that group is approximately 6.5%. The figure presented with the abstract of reference 13 (pg. B-5) shows a particualte matter emission value of 35 mg/kg oil at 6.5% CO_2. An average improvement to a level of 10% CO_2 would result in a reduction of TSP emission to 20 mg/kg oil or by 43%.

Table XI. Estimated SO_2 and Particulate Matter Emission Reduction for the U.S. (1978)

	Emission Reduction from Residential, Commercial & Institutional Oil Users, total U.S.	
	%	tons
SO_2 (6% reduction in 40% of all installations)	2.4	27,840

For the reduction of hydrocarbons, no numerical value can be given. It would be interesting to know more about it, but the inspection method used in Europe is only qualitative.

Results of field investigations done in the U.S. have to be available to either confirm or dispute the assumptions made here. Once a good data base for the efficiency improvements and the emission reductions is established, an inspection/maintenance program design effort would be easily justified. The program design needs to take into account the technical skills of the professional group executing the program and probably some additional incentives besides the fuel cost savings. Maintenance of energy systems in general has been neglected in the past. It has been only recently that maintenance has again been recognized as a cost saving activity. Besides prolonging the lifetime of the equipment and lowering breakdown rates, fuel cost savings are beginning to be viewed as a benefit of increased maintenance efforts. The timing seems good to get inspection/maintenance programs designed, tested, and accepted by the public if the overall benefits to the oil user can be better documented.

7. Acknowledgements

The authors would like to thank Robert E. Hall, Industrial Environmental Research Laboratory, USEPA, for his support and encouragement for the ongoing analysis of inspection/maintenance programs in West Germany and Switzerland. Also highly appreciated are the additional detailed documentations received from Walter Hess, health inspector of Zurich and from Mr. Gliwa at the Landesanstalt fur Immissionsschutz, Essen.

REFERENCES

1. United Nations, "World Statistics in Brief", 3rd edition, N.Y., 1978.
2. National Geographic Society, "Energy, a Special Report on the Public Interest", Washington, DC, February 1981.
3. Federal Dept. of Transportation and Energy, "Energy Consumption of Switzerland 1979", Berne 1980.
4. U. Roth, Th. Gisberg, W. Martin, E. Ledergerber, "Influences on the Settlement and Land-Use by Developments in the Energy Sector", Ministry for Land-Use, Housing , and City Planning, Bonn-Bad Godesberg 1976.
5. Energy and Environmental Analysis, Inc., "End Use Energy Consumption Data Base:, Dept. of Energy, Washington, DC, June 1978.
6. Swiss Association of Heating Equipment Manufacturers, "Service Statistic as of 1980", internal report, June 1980.
7. R. Madler, "Public Complaints About Air Pollution as an Instrument of a Control Policy", Z. fur Gesundheitstechnik, November 1975, February 1976.
8. W. Hess et al., "Oil Heating Inspection in the City of Zurich", Schw. Blaetter fur Heizung und Lueftung 1979,
9. Swiss Federal Government, "Proposal for an Environmental Protection Act", Berne, Switzerland, October 31, 1979.
10. Federal Government of Western Germany, "First Ordinance for Execution of the Federal Air Pollution Control Act", August 28, 1974.
11. Swiss Federal Dept. of Transportation and Energy, "Requirements for Inspection of Combustion Efficiency of Heating Installations", preprint of draft proposal, January 1980.
12. Dept. of Air Pollution Control of the State of Basel, "Oil Heating Inspection in Basel", internal report, February 1980.
13. P. Davids, "Emission Reduction and Fuel Savings for Oil Heating Installation", Z. Hyg. Gesundheitstechnik, Bauphysik 96(2): 33, 1975.
14. Dept. of Public Health of the City of Zurich, "Summary of the results of Oil Heating Inspections",1976 to 1978", internal report, July 1979.
15. W. Hess, "Millions Wasted Inefficiently", Schw. Handelszeitung Nr. 3, January 20, 1977.
16. W. Hess, "First Results of Combustion Efficiency Inspection in the City of Zurich", unpublished paper, 1980.

17. R. Madler, "Cost-Benefit Analysis of Governmental Oil-Heating Inspection Programs Versus Porposal for Required Service and Maintenance by Private Enterprises", consulting report, July 1980.
18. USEPS, Deputy Assistant Administrator's Report on Ambient Monitoring Activities, Air Portion, U.S. Environmental Protection Agency, Washington, DC, 1980.

Appendix A
SUMMARY OF LEGAL SITUATION
IN WEST GERMANY AND SWITZERLAND

West Germany

In 1974 A Federal Law for Environmental Protection was enacted ("Bundes-Immissionsschutzgesetz). In a first ordinance to that law, also in 1974, standards for heating equipment were set and its maintenance was regulated. The following extracts deal with oil-fired heating systems:

Standards:

smoke level (Bacharach):	3 or better
CO_2 % for existing installations:	7% or higher
CO_2 % for new installations:	10% or higher
Hydrocarbons:	not detectable with prescribed method

Inspections:

- annually through chimney sweeps
- chimney sweeps report noncomplinances with regulating agency

Instrumentation for Inspection:

- description which corresponds to the Bacharach pump or other mechanical pumps
- smoke level definition - same as US Bacharach scale
- Forms prescribed
- Hydrocarbon test - on filter paper of smoke pump, chromatography concentrated towards rim, visual detection through yellowish color

Enforcement:

Fines, no limits reported

Switzerland

In the near future, Switzerland will enact a Federal Environmental Protection Law. In addition to the law, many ordinances have already been prepared and published as guidelines. Many state and communal governments have declared some of the guidelines mandatory and enforce them.

Proposed Environmental Protection Law:

- authority to require periodic inspection for oil-fired heating systems rests with the cabinet
- limits will be set on the sulfur content of fuel oils

Guidelines:

- Combustion efficiency of heating installations is discussed in 4.2, Table II.
- Bacharach smoke level standards for comparision are defined as in ASTM 2156-65 plus additional requirements for printing, screen resolution, glossiness, whiteness of paper, resulting in a much higher quality.
- air quality standards SO_2;
  annual average of 1/2 h values - 60 micrograms/m^3
  95% percentile of 1/2 h values - 300 micrograms/m^3
- construction and design of chimneys and stacks;
  detailed mathematical treatment for stacks of heating systems above approximately 80 gal/yr capacity
- general rules and minimum dimensions for chimneys of smaller installations
- inspections of oil-fired heating installations

Enforcement in Switzerland

Proposed Environmental Protection Law, general formulation (not specified for the case of noncompliance with oil-heating standards):

if noncompliance is intentional:	prison up to 6 months
if noncompliance is through carelessness:	fine up to SFr. 20,000 (US $10-12,000)

Appendix B

ABSTRACTS OF MOST RELEVANT PUBLICATIONS USED IN THIS REPORT

6. Associations of Swiss Manufacturers of Heating Equipment (VSO and KRW): Economy of Oil-Fired Boilers

These associations discuss the new Swiss guidelines for technical design of burners and boilers. These guidelines standardize shape and size of flames of burners in relation to capacity, and shape and size of combustion chambers of boilers to achieve symmetrically and evenly distributed energy densities on the heat exchanger surfaces. The associations welcome these new guidelines.

7. R. Madler: Treatment of Public Complaints About Air Pollution as a Task for Communal Governments, Gesundheitskchnik:, November 1975, and February 1976.

Some ideas about the relationship between public concern about air pollution and the official air pollution control policy of governments are presented. The history of oil heating inspection programs is outlined, and still today is closely related to those public complaints about air pollution.

Air pollution emitted by oil heating installations is easily detectable by the human senses; soot has an optical impact on its environment, hydrocarbons (from oil heating) are detected as bad odors. Even today, the City of Zurich receives nearly a thousand complaints annually concerning 3-400 heating installations which are emitting excessive hydrocarbons or soot.

8. W. Hess: Oil-Heating Inspection in the City of Zurich, Summarized Results of the Heating Periods, "Schweizeirsche Blatter fur Heizung und Lufhing", 1979.

This is probably the most extensive publication about inspection programs. In great detail, the influences of the following characteristics on air pollutant emissions are investigated:

- age of oil-burner and boiler
- revolutions of burner fan motors
- material of boilers (sheet metal versus cast iron)
- burner capacity
- periodic maintenance by manufacturer (subscription)
- market share

The information in this publication is discussed in detail in the text.

12. Air Pollution Agency of the State of Basel-Land:
Oil Heating Inspections, Results of the Heating Period 1978/79, internal report, sent to related professionals.

The inspection program in Basel-Land is similar to the Zurich program. The major difference is the inspection period: 1 year in Basel-Land, compared to two years in Zurich. As explained in part 5.1 of the text, this difference may explain various findings of the relative inspection programs. The development of the percentage of installations exceeding standards is presented in Figure 2.

Similar to the publications of W. Hess[8,15,16], a few findings about influencing factors are reported:

- capacity of installation
- periodic maintenance by manufacturer (subscription)

The results obtained from this inspection program are statistically not significantly different from the Zurich results.

13. P. Davids: Emissions Reduction and Fuel Savings for Oil-Fired Heating Systems, "Zeitschrift fur Hygiene, Gesundheitsechnik und Bauphysik", February 1975.

In addition to the previously discussed publications from P. Davids are results about the interdependence of air pollution emissions and age of the installations. Installations built in 1955 have an average smoke level of 2.1, installations built in 1973 have a smoke level of only 1.7. Also, certain boiler-burner combinations (brands) have higher or lower smoke numbers at the same CO_2% level. For the total population, however, the smoke numbers are lowest between 10% and 13% CO_2.

The newly reported emissions (specific numbers, averages of an unknown sample) of gaseous air pollutants are:

CO: 1.5 g/kg oil (relation to CO_2 % not reported)

NO_x: 2.1 g/kg oil (no relation to CO_2 %)

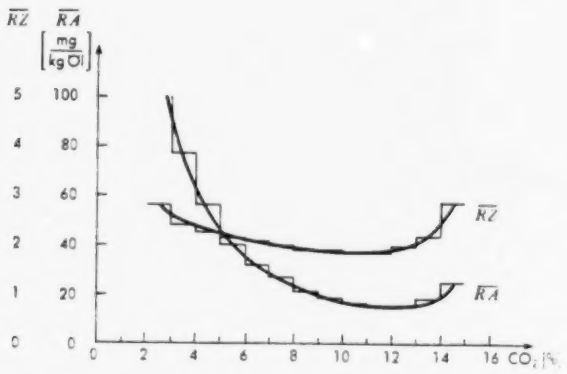


Figure 1. Interdependence of CO_2 with Smoke Numbers (RZ) and TSP Emissions (RA).

15. W. Hess: Millions Uselessly Wasted, "Schweizerische Handelszeitung", March 1977.

The author summarizes some important effects of oil heating systems inspections for air pollution and combustion efficiency in Zurich, Switzerland:

air pollution: SO_2 - 49 t/yr (1% of total)
Soot - 1.7 t/yr (60% of total)
C_xH_y - 176 t/yr (approx. 35%)

fuel savings: oil - 10.6 mill liter (25% of total)

These numbers are based on a sample of 17,000 inspections for air pollution, but only 450 inspections for fuel savings. However, they are one of the most precise information sources about the positive effects of inspection programs.

16. W. Hess: First Results of Combustion Efficiency Inspections in the City of Zurich, unpublished paper, 1980.

The main results are discussed in the text, part 5.2. In addition to the distribution of combustion efficiencies, the distribution of stack gas temperatures may be of interest:

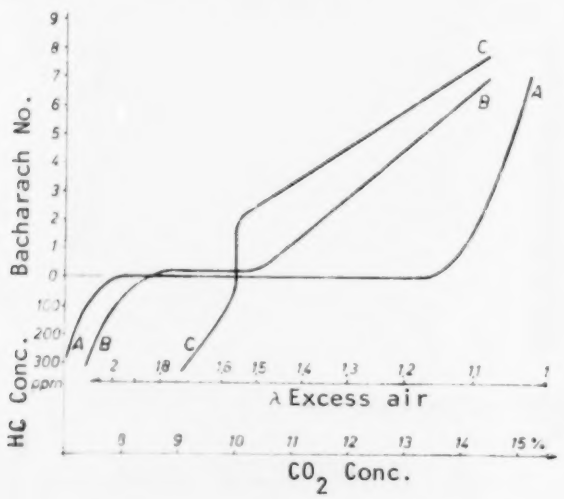
% of installations	temperature range °C	°F
2	<150	<302
23	150-199	302-390
45	200-249	392-480
23	250-299	482-570
6	300-349	572-660
2	≥350	≥662
average:	231	448

(sample size: 3000)

R. Hunziker: Surveillance of Economical Operation of Oil Heating Installations, Dokumentation 16, Swiss Association of Engineers and Architects

An instrument is described for continuous monitoring of oil heated boilers. Soot and unburnt hydrocarbons are monitored. The instrument produces an alarm if any one of these components exceeds the standards.

The author emphasizes the relationship between air pollution emissions and combustion efficiency. Results from lab tests support the positive relation between the two. For three different types of burners (not specified) the following curves were found:



The alarm monitor allows the installation to maintain a better operating range and initiates adjustments/repairs when necessary. The author claims a permanent combustion efficiency of 90-95% for monitored installations.

Annual Report of the Environmental Protection Agency of the City of Berne, Switzerland, 1979.

In 1978/79 3509 inspections were performed and 15% violations of air pollution standards were found. The violations increase with the age of the installations. From previous periods, the following results are reported:

	# of inspections	% violations
1974/75	4034	32
1975/76	3546	29
1976/77	2328	23
1978/79	3509	15

More than half of these violations are because of hydrocarbons. Significant differences between manufacturers are reported:

best brand: 8% violations

worst brand: 57% violations

P. Davids: Success of Oil-Heating Inspection in "Nordnein-Westfalen", (West German State), "Das Schornsteinfegerhandwerk", April 1974.

New results from the heating period 1972/73 are reported. The main concern in this paper (published after the 1973 oil price increase) is the possible savings of fuel. Combustion efficiency (average of inspected installations) improved since 1964/65 from 77.5% to 83.1%. The average capacity of oil burners (compared with mode of size distribution reported one year earlier: 1.1 gal/hr) is approximately 1.7 gal/hr.

Because of the successful implementation of the inspection program, the legally required chimney cleaning (number of chimney sweeps) was reduced (reduction not specified).

The author suggests a further increase to an average combustion efficiency of 88% as an objective for the near future. Additional fuel savings (Nordheim-Westfalen) would amount to 160 million gallons per year.

P. Davids, et. al.: Possibilities for Reduction of Soot and Odors Emitted by Oil-Fired Heating Systems by Process Optimization and Mechanical Improvements, "Gesundheits-Ingenieur", September 1973.

Results of inspections on 38,000 installations in the heating period 71/72 are evaluated. Soot and odor emissions can be reduced to a minimum level through operation of the installations with CO_2 concentrations between 10 and 13%. The improvements compared to today's situation is considerable. The simultaneous increase in combustion efficiency reduces emissions further, though not in the same amount. Efficiency and fuel conservation is of interest for the owners of the installations.

Different brands of burners and boilers differ significantly in air pollutant emissions and combustion efficiency. Mechanical improvements on insufficient designs are feasible. The author supports technical and emission standards for burners and periodic maintenance. He expects then that almost all installations will operate with maximum efficiency and minimal air pollution.

Numerical results (38,000 installations, West Germany, 1971/72):

installations exceeding emission std:	10%
installations exceeding hydrocarbon emission std.:	3%
minimum of smoke level in function of CO_2:	smoke level 2 at 11% CO_2
average CO_2 %:	8.5%
most frequent burner capacity (mode of size distribution):	1.1 gal/hr

L. Marci: Possible Savings for Heating Installations and Their Limitations, "Installation", May 1976.

Construction and design of installations are important for efficiency in two ways:

- maximum efficiency under optimal conditions, like test labs, etc.
- transfer of these desirable efficiencies to operations in practice in the long run with infrequent maintenance and other adverse conditions

The elements affecting efficiency are discussed and evaluated:

- stack gas temperature (low, just above acid condensation temperature)
- combustion air temperature (as high as possible, recirculation of heated air)
- excess combustion air
- heat radiation losses of boilers and hot water pipes, related to intermittent burner operation
- effect of "flue dampers"

The author combines all these considerations in calculating total annual efficiency of installations. He presents three important recommendations:

- demand for high quality of installations in construction and replacement
- high quality and advanced design in manufacturing
- periodic maintenance

Swiss Association of Heating Equipment Manufacturers (VSO):

"Service Statistics as of March 30, 1980", internal Memo

Besides the information for Figure 1 (size distribution), other numerical data in the report are:

- 30% of all installations are periodically (once per heating period) maintained according to a long term contract between owner and manufacturer
- In Switzerland there are 1110 service technicians for oil and gas burners, 350 of them are federally licensed. This corresponds to 622 burners installed in Switzerland per service technician.